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A SOLAR EXTREME ULTRAVIOLET TELESCOPE AND SPECTROGRAPH FOR SHUTTLE/SPACELAB*

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Abstract. An instrument for advanced studies of the solar corona is described. Its optical system provides nearly stigmatic imaging of selected portions of the Sun over the spectral range from 22.5 to 44.0 nm. Both spectroheliograms and emission line profiles of coronal features will be obtained over a wide range of coronal temperatures.

This paper describes the capabilities and anticipated scientific application to solar observations of a Solar Extreme Ultraviolet Telescope and Spectrograph (SEUTS) that has been selected by NASA for definition and, it is expected, flight on a Shuttle/Spacelab mission. (The instrument was proposed in response to a NASA Announcement of Opportunity issued in June 1978 (Neupert *et al.*, 1978)). We will summarize the scientific objectives and functional design of the instrument and then discuss how it will be applied to investigation of major questions concerning the solar corona.

The *scientific investigations* that will be carried out with the SEUTS address several fundamental problems of solar physics:

– The energy and mass balances in closed magnetic field regions in the corona and the processes by which these regions are heated.

– Mass and energy transport into the solar wind.

– The characteristics of the emergence and evolution of coronal active regions and their relation to flare activity and coronal holes.

Our prime scientific objectives require EUV observations with high spectral ($\Delta\lambda \approx 0.005$ nm) and spatial ($\Delta s \approx 2$ arc sec) resolution *simultaneously* over a wide range of solar temperatures (1×10^5–2×10^7 K) and over an extended field of view. We intend to:

(1) Observe emission line profiles and intensities over a wide range of transition zone and coronal temperatures for many types of features (active regions, quiet

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sun, coronal holes, etc.) in order to correlate turbulent and directed mass flows with the coronal conditions of electron temperature and density in which they are found.

(2) Search for periodic and aperiodic (possibly impulsive) intensity variations of spectral lines as a function of temperature that may be indicative of wave processes or other forms of energy injection into the corona.

(3) Observe coronal and transition-zone loop configurations and their changes prior to and following flares to assess the role that coronal magnetic fields and their possible instabilities play in the flare phenomenon.

(4) Observe the EUV line-emission of flares as a means of identifying the locations of impulsive components, sources of mass for the high-temperature flare plasma and processes by which energy is converted and dissipated during the flare event.

The SEUTS *optical design* combines a Wolter Type II grazing incidence telescope having high EUV reflectivity with an aspheric near-normal incidence grating system which produces approximately stigmatic images of the solar image at each wavelength. A slit placed at the focus of the telescope acts as the entrance aperture for the spectrograph and defines the array of spatial elements that will be refocussed, at each wavelength, in the final focal plane. The principal optical paths can be traced in Figure 1a.

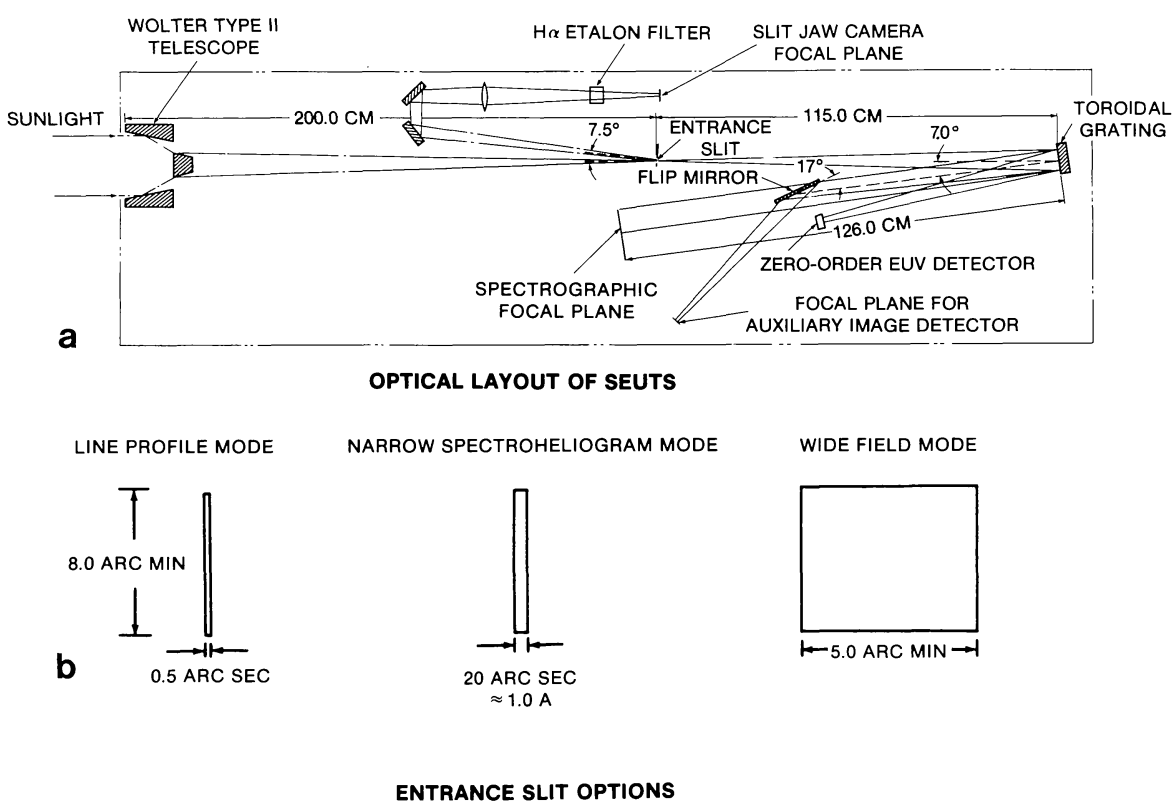

Fig. 1. (a) Schematic outline of optical and detector systems currently planned in the Solar Extreme Ultraviolet Telescope and Spectrograph (SEUTS). (b) Outline of spectrograph slit configuration to be located at the focus of the SEUTS Wolter type II telescope.

The current SEUTS design incorporates in $f/22$ telescope having a focal length of 450 cm and a collecting area of 150 cm^2. Angles of incidence range from 10° to 13°. The spectrograph has a toroidal grating ($R_s = 120.002$ cm; $R_t = 120.967$ cm) with 3600 l mm^{-1} used in a slightly magnifying configuration. The instrument can achieve a spatial resolution of 2 arc sec (photographic plate scale of 24 microns per arc sec) and spectral resolution of 0.005 nm (4550 microns per nm) over a 22.5 nm–44.0 nm spectral range and a 4 arc min field of view. The photographic focal plane is located to optimize spectral resolution over the spectral range. This optical design provides a flexible data format (via commandable selection of one of four entrance apertures) that can be employed to optimize scientific observing programs. The present design (Figure 1b) incorporates:

(1) A line profile mode ($\Delta\lambda \approx 0.004$ nm in the Rowland plane) yielding stigmatic spectra over a geometric field of view (FOV) of 0.5 arc sec × 8 arc min. In this mode the SEUTS will produce spectra from approximately 22.5 to 44.0 nm.

(2) A spectroheliogram mode with a 0.3 × 8 arc min FOV for many strong lines. The slit width (0.3 arc min) corresponds to about 0.1 nm. Spectrally non-overlapping solar images may be built up simultaneously in many strong lines by displacing the pointing direction 0.3 arc min between observations.

(3) A wide-field mode (5 × 8 arc min FOV) for flare studies, with spatial resolution in the direction of dispersion governed by the Doppler widths of the spectral lines. In this mode, the instrument is similar to the S082A slitless spectrograph on Skylab.

(4) A combination mode (not shown) providing spectroheliograms (Mode 2) over most of 0.3 × 8 arc min FOV but with line profile observations (Mode1) in the central (0.5 arc sec wide by 0.8 arc min long) portion of the field where spectral resolution is best.

The SEUTS also incorporates an Hα slit-jaw monitor and an EUV exposure meter that, respectively, facilitate the selection of targets and the optimization of exposure times. The optical paths for these systems are also shown in Figure 1a. Also shown is an auxiliary imaging detector system that will be evaluated during the first SEUTS flight.

There are two main scientific reasons for selecting the region between 22.5 and approximately 44.0 nm for high spatial and spectral resolution observations. The first is the presence of spectral lines spanning a very wide range of temperatures, from lower transition zone (e.g., He II 30.4 nm) up to coronal flare temperatures (e.g., Fe XXIV 25.5 nm and Ni XXVI 23.4 nm). Lines of He II, C IV, N IV, O IV, and O V are emitted at lower transition-zone temperatures (6×10^4 K–2.2×10^5 K). The upper transition zone emits lines of Mg VI–Mg VIII (5×10^5–6×10^5 K). The quiet corona can be studied in lines of Si IX – Si XI, Fe IX – Fe XIV, and S XII (1×10^6 K–2×10^6 K). Active regions are represented by lines of S XIII, Fe XV, Fe XVI, and Ni XVIII (2.5×10^6 K–5.5×10^6 K). During solar flares, lines of Ca XVIII, Fe XXI – Fe XXIV, and Ni XXVI (7×10^6 K – 2.5×10^7 K) appear strongly. The second reason is the availability of many spectroscopic diagnostics that will allow determination of electron density, differential emission measures, mass flows, and nonthermal random mass-motions ('turbulence') of many solar features that extend into the corona. (For details see paper by M. Malinousky-Arduini in this same issue) Every region of the solar atmosphere above 4×10^4 K can be studied in the narrow 22.5 to 44.0 nm range, thereby obtaining uniformly good optical performance over the entire wavelength band, conserving precious film, and providing the data for inflight calibration.

The full width at half maximum (FWHM intensity of an optically thin line due to thermal, non-thermal and instrumental broadening is given by

$$\mathrm{FWHM} = 2\sqrt{\ln 2}\,\frac{\lambda}{c}\left(\frac{2kT_i}{M} + \xi^2 + \frac{c^2 \Delta\lambda_I^2}{4(\ln 2)\lambda^2}\right)^{1/2}, \tag{1}$$

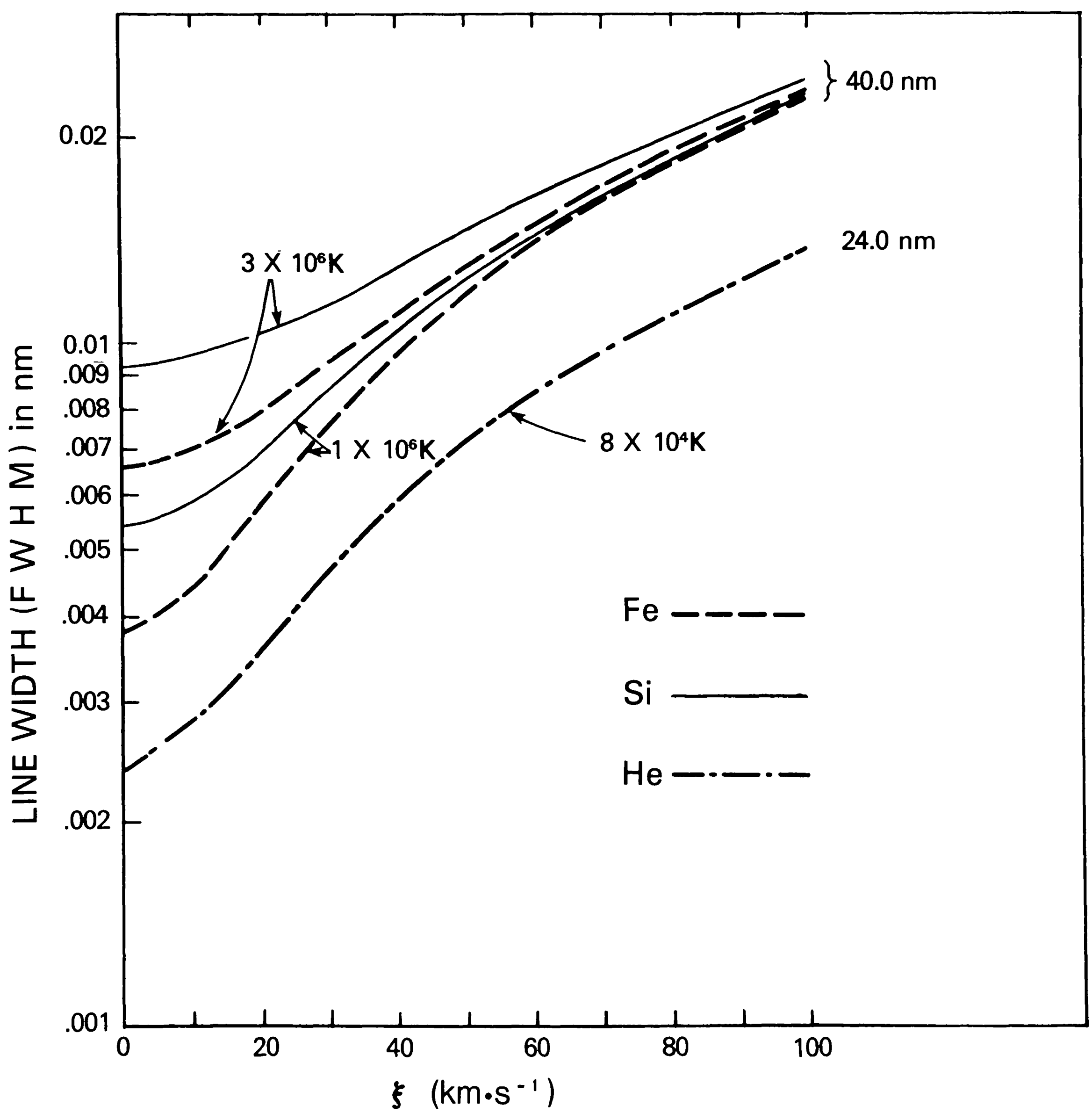

Fig. 2. Spectral line widths (full-width half maximum) as a function of plasma electron temperature and non-thermal (turbulent) velocity for Fe, Si, and He emission lines at typical EUV wavelengths.

where λ is the wavelength, c is the speed of light, M is the ion mass, T_i is the ion temperature (assumed equal to the electron temperature T_e), ξ is the most probable non-thermal velocity, and $\Delta\lambda_I$ is the instrumental FWHM. Equation (1) assumes a gaussian distribution for both thermal and non-thermal components. Excluding opacity, the broadening to be expected for coronal lines in the 200–400 Å region can be estimated from the typical non-thermal velocities deduced by Cheng *et al.* (1979). For the quiet Sun transition zone, line widths can be estimated from the values of ξ given in a number of papers, e.g., Mariska *et al.* (1979). For flares, the FWHM of the forbidden line of Fe XXI at 135.4 nm reported by Doschek *et al.* (1975) provides a guide to the widths of lines of highly ionized flare ions at shorter wavelengths. For the corona and transition zone the widths correspond to $\xi \approx 20\ \mathrm{km\ s^{-1}}$; and for flares the value is on the order of $\xi \geqslant 50\ \mathrm{km\ s^{-1}}$.

The expected line widths may be illustrated clearly in graphical form. The FWHM of hypothetical lines of iron, silicon and helium are shown in Figure 2, as a function of λ, T_e, and ξ, as calculated from Equation (1). In order to measure a profile adequately, it is necessary that the instrumental FWHM ($\Delta\lambda_I$) be no wider than about $\frac{1}{3}$ of the true line width. Thus, if $\Delta\lambda_1 = 0.004$ nm at 40.0 nm, adequate resolution will be achieved for most lines.

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